THE NASA/JPL AIRBORNE SYNTHETIC APERTURE RADAR SYSTEM

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INTRODUCTION

The NASA/JPL airborne SAR (AIRSAR) system operates in the fully polarimetric mode at P-, L- and C-band simultaneously or in the interferometric mode in both L- and C-band simultaneously. The system became operational in late 1987 and flew its first mission aboard a DC-8 aircraft operated by NASA's Ames Research Center in Mountain View, California. Since then, the AIRSAR has flown missions every year and acquired images in North, Central and South America, Europe and Australia.

In this paper, we will briefly describe the instrument characteristics, the evolution of the various radar modes, the instrument performance and improvement in the knowledge of the positioning and attitude information of the radar. In addition, we will summarize the progress of the data processing effort especially in the interferometry processing. Finally, we will address the issue of processing and calibrating the cross-track interferometry (XTI) data.

INSTRUMENT CHARACTERISTICS

In AIRSAR, transmit polarization diversity is achieved by alternately transmitting the signals using horizontal or vertical polarizations. Receive polarization diversity is accomplished by measuring six channels of raw data simultaneously, both H and V polarizations at all three frequencies. The video data are digitized using 8-bit ADCs, providing a dynamic range in excess of 40 dB and, together with navigation data, stored on tape using high density digital recorders. The AIRSAR system also includes a real-time processor capable of processing any one of the 12 radar channels into a scrolling image. In addition to checking the health of the radar, the scrolling display is also used to ensure that the correct area has been imaged. Table 1 provides a summary of the AIRSAR system characteristics. AIRSAR can be operated in many different modes due to the complexity and flexibility of the instrument. The evolution of these radar modes is summarized in the following section.

“1’able 1. Summary of AIRSAR system characteristics. The parameters in ( ) apply to 40 MHz chirp bandwidth configuration.

	P-band	L-band	C-band
Chirp Bandwidth (MHz)	20 (or 40)		
Chirp Center Freq. (MHz)	438.75 (427.5)	1248.75 (1237.5)	5298.75 (5287.5)
Peak Transmit Power (dBm)	62	67	60
Antenna Polarization	H/V dual microstrip		
Antenna Gain (dBi)	14	18	24
Azimuth Beamwidth (deg)	19.0	8.0	2.5
Elevation Beamwidth (deg)	38.0	44.0	50.0
Antenna Size (m)	0.9 x 1.8	0.5 x 1.6	0.2 x 1.4
ADC Sampling Rate (MHz)	45 (90)		
Data Rate (MB/s)	10		
NE Sigma0 (dB)	- 4 5	“ ,	-35
Nominal Altitude (m)	8000		
Nominal Velocity (Knots)	450		
PRF/Polarization Channel	1 (programmable) x ground speed in Knots		
Slant Range Resolution (m)	10 (5)		
Azimuth Resolution (m)	1		
Ground Range Swath (km)	1 0 - 1 5		

RADAR MODES

When AIRSAR flew its first scientific mission in 1988, it was capable of imaging sites in P-, 1,-, and C-band simultaneously in polarimetric mode or L- and C-band along-track interferometric (ATI) mode. ATI mode was successfully used to image ocean currents ancl waves moving in the radar line-of-sigh{ direction, Since then, more antennas and antenna switching networks have been installed to accommodate cross-track interferometric (XTI) and bistatic modes. XTI mode was successfully used to generate topographic maps of areas of interest whereas the bistatic mode was successfully used to collect data in conjunction with ERS-1(CVV) and SIR-C (1 ,VV ant] CVV). Figure 1 shows the relative location of all the antennas currently available on the DC-8 and their polarization. ‘1’able 2 summarizes the evolution of these radar modes.

As shown in Table 2 and Figure 1, the baseline of the C-band ATI mode was shortened significantly in 1991 by pairing up the, newly added C-bt antenna with the C-SAR antenna in an effort to increase the sensitivity to shorter decorrelation time of ocean currents. Prior to 1995, the single frequency XTI mode (XTI I) was operated with one transmit antenna that provides the best possible SNR. The reason is that the transmit path via the C-tp antenna is 3 m shorter than that of the C-bt antenna, hence giving us better SNR. Since 1995, we have been experimenting with alternating the transmit antenna between the top and the bottom antennas. This effectivel y doubled [he base.]i ne and initial data analysis showed that the longer baseline produced DEMs (digital elevation models) with reduced RMS height error as expected. in addition, the newly added 1,-band XTI mode produced DEMs of s] ight l y higher RMS height error due to shorter baseline length (scaled by wavelength) compared to those of C-band XTI mode, although much work remains to be clone to calibrate the L-band XTI mode.

To produce accurate DEMs, we need to know the baseline precisely. To do this, we have also upgraded the inertia] Navigation System (INS) and the. Global Positioning System (GPS) receiver in order to have more accurate knowledge of the location and attitude of the antennas. The upgrades are described in the nex(section.

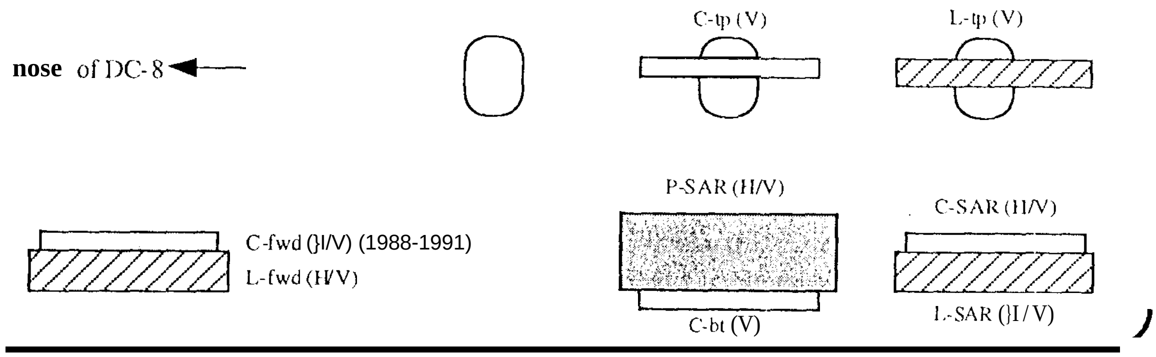

Figure 1. View of relative location of the antennas (not to scale).

'liable 2. Summary of the available radar modes for AIRSAR.* Since 1994, P-band is allowed to transmit in the U.S only when the radar is in 20 MHz chirp bandwidth mode. If special clearance is obtained prior to the flight, P-band is then allowed to transmit in 40 MHz chirp bandwidth mode also.

Mode	Date	P-band*		L-band		C-band	
		TX	RX	TX	Rx	TX	RX
POLSAR (quad-pol)	1988 - present	P-SAR (H/V)		L-SAR (H/V)		C-SAR (H/V)	
ATI	1988 - 1990	P-SAR (H/V)		L-fwd and L-SAR		C-fwd and C-SAR	
ATI	1991 - present	P-SAR (H/V)		L-fwd and L-SAR		C-bt (V) and C-SAR	
X"J'11	1991	P-SAR (H/V)		L-SAR (H/V)		C-bt	C-bt / C-tp
XT11	1992 - 1995	I'-SAI{ (H/V)		L-SAR (H/V)		C-tp	C-bt / C-tp
XTI1 - ping pong	1995	P-SAR (H/V)		L-SAR (H/V)		C-bt and C-tp	
XTI2	1995	P-SAR (H/V)		L-tp	L-tp / L-bt	C-tp	C-bt / C-tp
XTI2 - ping pong	1995	P-SAR (H/V)		L-tp and L-bt		C-bt and C-tp	

NAVIGATION SYSTEM

'l'he original navigation system of AIRSAR consisted of a Honeywell INS with a ring laser gyro that determined the attitude of the aircraft and a Motorola Eagle 4-channel GPS receiver that provided the positioning information (latitude and longitude) of the aircraft. As technology advanced and our need for more accurate positioning and attitude information became more stringent, wc purchased a ncw Motorola Six-Gun GPS receiver and a new Honeywell Integrated GPS and INS (IGI) in 1994. The Six-Gun GPS receiver has six channels and a much more stable clock compared to the old unit ancl provides positioning accuracy of 100 m using CA code. 'l'his receiver was integrated in the radar in 1994. The Honeywell IGI has a smaller and more sensitive ring laser gyro integrated with a GPS receiver capable of receiving the more ac.curate but restricted Precise Positioning Service (PPS) data. The specifications on this unit are: 0.02" heading accuracy, 0.01" roll and pitch accuracy, 0,03 m/s velocity accuracy per axis, anti 16 m positioning accuracy with PPS. The IGI was installed on the DC-8 in 1994 but the data were recorded off-line and were not available in the radar header until the. 1995 flight season.

in addition, we have also experimented with differential GPS by using a Turbo Rogue GPS receiver on the aircraft in conjunction with another Turbo Rogue receiver on the ground. 'l'his experiment is usually supported by the GPS experts from another section at JPL and requires special post-processing to obtain positioning accuracy of better than 1 m.

DATA PROCESSING

A variety of processors and processing techniques are utilized to process AIRSAR data to imagery. A real-time correlator is part of the AIRSAR radar flight equipment (the Aircraft Flight Correlator) and is used to produce low resolution (approx. 25 meter) two look survey imagery. The same on-board equipment is used to generate a slightly higher resolution (15 meter), 16 look image of a smaller area (12 km x 7 km) within 10 minutes of acquisition using the quick-look processor. These on-board processors are useful for assessing the genera] health of the radar and the success of data taking in real-time.

Final processing of selected portions of the data to high quality, fully calibrated image products happens in the weeks and months following a flight campaign. Currently, users may request images from two different operational processors, the synoptic processor and the frame processor. In the synoptic processor, the user specifies three data channels to be processed. About five minutes of raw data from each of the three selected channels arc processed to 16 looks and amplitude-only image strips, covering about 40 km along track. in 40 MHz mode, the image strips would be 8 looks ant] 20 km long. These image strips cover about 9 km in the slant range direction for the 20 MHz mode and 4.5 km for the 40 MHz mode.

In terms of frame processing, wc currently support two processor versions: the AIRSAR processor (version 3.5x) and the new integrated processor (version 5.x), which is still under development (especially in XTI calibration). 1995 has been a transition year for' the AIRSAR ground processing facility. The new integrated processor was developed mainly to process XT] data routinely since XTI mode has become increasingly popular. In order to do so, wc needed a ncw processor that tracks and compensates for the motion of the aircraft since uncorrected motion translates into baseline error between the two ante.nnas, which results in height error in the DEM. in addition to motion compensation, the new integrated processor is also capable. of generating images with full range swath as opposed to half range swath with the version 3.5 processor. The XTI processor still needs an accurate algorithm to determine absolute phase. In addition, better calibration is required to remove systematic height errors in DEM.

As with the previous version, the integrated processor processes one minute of raw data of all available data channels into absolutely calibrated images in compressed Stokes matrix format that contains all the polarization information. If C-band cross-track interferometer data arc available for the data take, the integrated processor will generate a digital elevation model and a local incidence. angle map. By using the local incidence angle map, all output images will be geometrically and radiometrically corrected taking the topography into account and resampled to ground range with a 10 m by 1() m pixel spacing. The output images cover about 10-12 km in the range direction by about 10 km in the along-track direction for the 40 MHz mode, and about 20 km in the range direction by about 10 km in the along-track direction for the 20 MHz mode. Although the radar data rate allows us to image about 20 km in range swath for the 20 MHz mode, the increasing phase noise due to decreasing SNR as a function of incidence angle reduces the correlation between the two antenna channels. As a result, the RMS height error can be quite large in far swath due to poor SNR.

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The calibration of polarimetric data is well understood. Briefly, with the calibration tone in the receive chain anti corner reflector verification, wc arc able to consistently produce polarimetric images with better than 3 dB absolute, accuracy, better than 1.5 dB relative accuracy amongst the 3 radar frequencies, and better than 0.5 dB between the polarization channels, The relative phase calibration between the HH and VV channels is better than 10°.

The calibration of XTI data is much more challenging because various parameters, such as baseline vector, are involved in the XTI data processing. The absolute phase must be known in order to derive height information from the interferometric data without 2π ambiguity. The differential phase (between two channels) of the radar can be a function of system temperature. Therefore, we need to determine both absolute and differential phase for each data take. In addition, accurate knowledge of the baseline between the two antennas to a few mini-meters is necessary to generate accurate I) I{ Ms. We have successfully used the corner reflector array at Rosamond Dry Lake to determine the baseline for C-band antennas ant] arc currently working on the L-band antennas that wc started operating in 1995.

SUMMARY

in this paper, wc described the AIRSAR instrument characteristics, the evolution of the various radar modes, and improvement in the navigation system, In addition, we summarized the progress of the data processing effort and briefly addressed some of the challenges in calibrating the XTI data. Wc hope to resolve the phase calibration issues with the 1995 dual frequency XTI data in the near future so that wc could provide users with DEMs at L- and C-band routinely.

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